RESEARCH ON SMALL FIDUCIAL MARK USE FOR ROBOTIC MANIPULATION AND ALIGNMENT OF OPHTHALMIC LENSES

Fernàndez, X.* and Amat, J.**

*Research and Development Dept., Industrias de Óptica (INDO), Sta. Eulàlia 181, 08902 L'Hospitalet (SPAIN) T. +34 93 2982600 F. +34 93 2988663 E-mail: xavier@indo.es

**Automatic Control Dept., Universitat Politècnica de Catalunya, c/ Pau Gargallo 5, 08028 Barcelona (SPAIN) T. +34 93 4016972 F. +34 93 4017045 E-mail: amat@esaii.upc.es

Abstract - *Robotic manipulation and alignment of ophthalmic lenses during their manufacturing process can take advantage of machine vision location of small fiducial marks engraved or printed on the lens surface. Industry research efforts are currently devoted to obtain a proper fiducial mark design that optimises the reliability of robotic lens manipulation. In this paper the work in progress in this area is presented.*

1 INTRODUCTION

During recent years ophthalmic lens manufacturing industries have been improving their processes in order to increase productivity. Robotic lens manipulation tasks are some of the key actions in this improvement policy, because large productivity benefits are usually obtained when a manual manipulation operation is replaced by a robotic process.

Nonetheless, manipulation tasks during ophthalmic lens production must accomplish tight positional accuracy requirements, in order to guarantee a proper centring and alignment of the optical surfaces. We can emphasise, among others, the following manipulating tasks [1]:

- Loading one-surface-finished lens onto the second-surface-working machine. The proper alignment between the first lens surface and the working elements of the machine is required, in order to guarantee the optical correspondence between both surfaces.
- Cutting finished lens perimeter to meet the shape of the spectacle frame. Lenses must be manipulated in a way that the optical centre and axis is accurately positioned with respect to the perimeter shape.
- Assembling the shaped lens on the selected frame, where a correct alignment between the lens and the frame is again required.

Positional accuracy requirements, derived from optical properties, are usually in the order of magnitude of 0.1 mm and 0.1 deg. Robotic manipulators (fig.1) can usually yield these values, provided that proper and reliable positional reference elements are available [2].

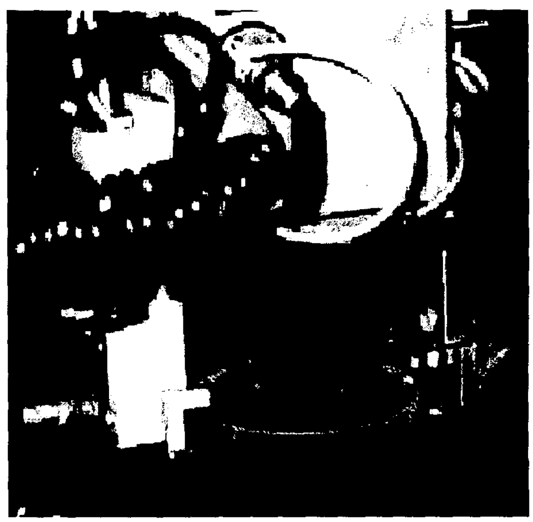

Fig. 1: Robotic manipulation of a lens aligned by mean of two small fiducial marks.

2 USE OF FIDUCIAL MARKS AS POSITIONAL REFERENCES

In order to establish the relationship between the lens co-ordinate system and the world co-ordinate system, in the early steps of lens manufacturing two small fiducial marks are printed or engraved on the upper surface, in order to settle the optical centre and axis through the position of these fiducial marks (fig.2).

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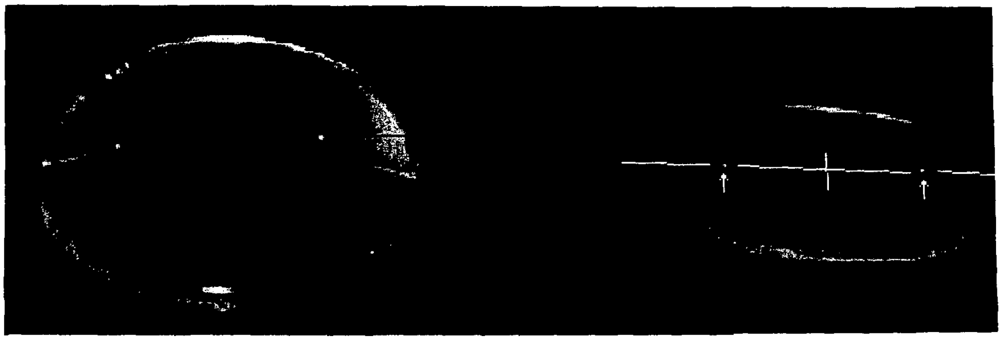

Fig. 2: Optical centre and axis can be determined through the location of the printed fiducial marks. (Left) A half-finished lens prior to working the bottom surface. (Right) A finished lens after cutting its perimeter to the shape of the frame.

Mark size is always a critical limitation: it must be kept as small as possible in order not to interfere with the field of view of the optical instruments which are used during production. The vision system, consequently, must be able to locate these small fiducial marks with reliability and accuracy [3].

Research work in this field has been addressed mainly to three areas: Determining the positional precision of the mark locating procedure, investigating the dependence of the detection reliability upon the mark size, and searching the optimal shape design for the fiducial mark.

3 POSITIONAL ACCURACY

Template matching techniques locate the position of the marks within 1 pixel accuracy. When a higher precision is required, the method of centroid can be used. Bose and Amir [4], showed that for small-size fiducial marks (less than 10×10 pixels) this method yields a maximum error of 0.3 pixels (in any direction), independently of the mark shape [5].

This is the positional accuracy we can expect for the localisation of the fiducial marks. When it is translated to the world co-ordinate system, under the resolution and mark layouts which are usually employed, this accuracy is smaller enough than the manipulation accuracy limit mentioned above [6].

4 DETECTION RESTRICTIONS DUE TO FIDUCIAL MARK SIZE

Whilst the required positional accuracy can be achieved, a major limiting topic is the loss of detection reliability which occurs when a fiducial mark is small in terms of the pixel lattice. This is a phenomenon that has been scarcely studied, marginally described in works devoted to astronomic image processing [7] or infrared imaging [8], where the term *apparent scintillation* is used to describe the problem.

The basic problem is shape and positional phase interference between the small mark shape and the pixel lattice arrangement. This phenomenon has been recently addressed by the ophthalmic industry with the aim of solving the loss of reliability of the use of small fiducial marks as a visual reference for the robotic manipulation of lenses.

From the point of view of the mark locating procedure, this interference causes, for small sized fiducial marks, the loss of the *translation invariance property* of the correlation or similarity peak, which locates the mark (fig.3). This means that two identical fiducial marks, placed on different positions in the scene, will yield different correlation peak values depending on their distinct subpixel position respect to the pixel lattice [9].

An experimental research about mark shape and size has been recently carried out [9]; from their results some interesting behaviours can be highlighted:

- When the fiducial mark size decreases, the lowest observed value of the correlation peak (denoted as *MLS* for *Minimum Locating Similarity*) decreases too.
- This loss of peak value will worsen detection reliability, because some locating peaks will not exceed the detecting threshold; thus misdetection probability increases when mark size decreases.
- Misdetection appears randomly, and prevents robotic manipulation to be continued until a manual corrective action has been performed. For a proper industrial operation, misdetection rates must be kept below 0.1%.
- There is a strong behaviour reliance on fiducial mark shape; two marks having equal size but different shape will show different loss of peak value. Consequently, there are shapes more reliable than others for the described task.

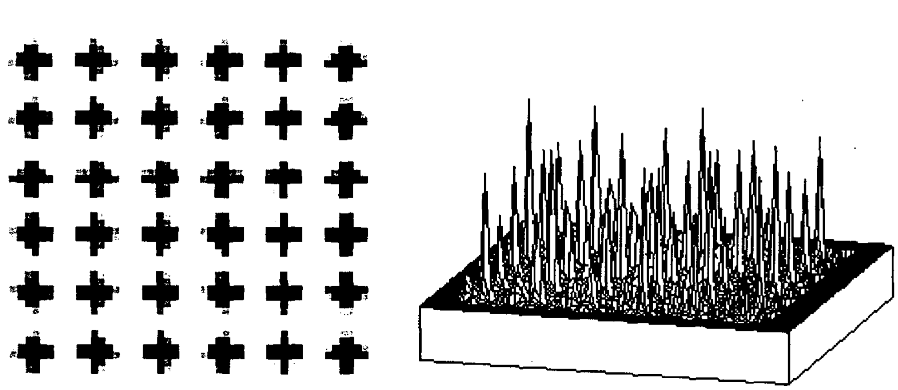

Fig. 3: (Left) Positional phase interference between a small fiducial mark and the pixel lattice. (Right) Resulting loss of translation invariance of correlation peaks.

5 DETECTION RELIANCE ON FIDUCIAL MARK SIZE AND SHAPE

From the experimental results and after a geometrical analysis of the mark and pixel lattice interference, the following relationship has been found [10]:

$$MLS_f = \left(1 - \frac{k_f}{L}\right)^2 \qquad (1)$$

where MLS_f is the minimum locating peak value for a fiducial mark f, k_f is a geometrical signature of the mark shape, independent of the size, and L accounts for fiducial mark size. This expression fits well to the experimental data [11].

Fig. 4: Several fiducial mark shapes used in the ophthal mic industry.

Several mark shapes have been evaluated: 45°-tilted square, ring, cross, square frame (fig.4). Among them, a 45°-tilted square has shown the lowest k_f value, that is, the lowest observed correlation peak for this shape is always higher than those of other shapes (fig.5).

Thus, it seems that the use of a 45°-tilted square shape for a fiducial mark would be advantageous because it allows a smaller mark size; in fact fiducial marks having this shape were efficiently detected at a size as low as 5×5 pixels. In addition, it has been observed that shapes having holes or concavities behave worse than their convex counterparts; this is the case of a square-frame shape, which become unreliable below a size of 10×10 pixels.

6 WORK IN PROGRESS FOR THE OPTIMAL SHAPE DESIGN

Current efforts are devoted to confirm and to prove that the 45°-tilted square shape optimises the detection behaviour among any possible fiducial mark shape, beyond the evaluated shapes above mentioned [10]. Additional research is being developed in order to explain and to predict the influence on mark detection reliability of other factors, such as search window size, and diffraction blurring caused on the image by the optical system [9].

The overall aim of the work will be to predict the detection behaviour of any possible fiducial mark used as a positional reference for the robotic manipulation of the lenses. This prediction will be an essential guide for the application developers in order to design a fiducial mark with the best features (shape, size) that optimise the trade-off between reliability of detection and small impact on the lens field of view.

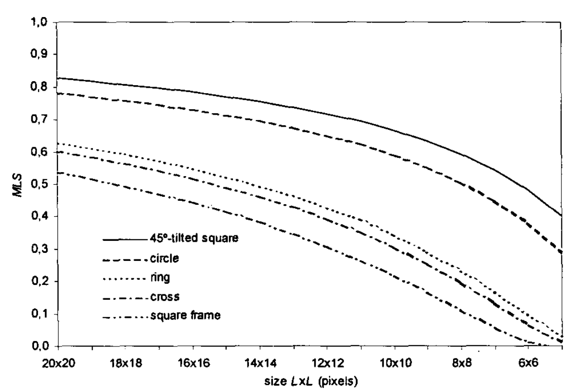

Fig. 5: Plot of eq. 1 (*MLS* vs. mark size) for five different fiducial mark shapes.

REFERENCES

[1] D.F. Horne, Optical Production Technology, Adam Hilger Ltd., 1983.

[2] B.K.P. Horn, Robot Vision, Mc. Graw-Hill, New York, 1986.

[3] X. Fernandez, S. Bosch, "Automatic visual inspection of centering marks engraved on ophthalmic lenses", Automated 3D and 2D Vision, Proc. SPIE Vol. 2249, pp.513-521, 1994.

[4] C.B. Bose, I. Amir. "Design of fiducials for accurate registration using machine vision", IEEE Trans. PAMI, Vol. 12, n° 12, pp. 1196-1200, 1990.

[5] I.E. Abdou, "Comment on the paper 'Elimination of systematic error in subpixel accuracy centroid estimation'", Optical Engineering 34(11), pp.3347-3348, 1995.

[6] X. Fernandez, J. Amat, "Robotic manipulation of ophthalmic lenses assisted by a dedicated vision system", ICRA'98 IEEE Conference on Robotics and Automation, 1998.

[7] T. Sziranyi, A. Boroczki, "Overall picture degradation error for scanned images and the efficiency of character recognition", Optical Engineering 30(12), pp. 1878-1885, 1991.

[8] T. Payne, "Apparent scintillation of sub-pixel targets imaged by focal plane arrays", Proc.SPIE Vol. 2743, pp. 264-275, 1996.

[9] X. Fernandez, "Detection and location determinig factors of minimum-size synthetic references by means of computer vision", PhD Thesis, Universitat Politècnica de Catalunya, Barcelona, 1998 (in press).

[10] X. Fernandez, J. Saludes, J. Amat, "Target shape influence on detection capability for poorly resolved targets in a template-matching scheme", Pattern Recognition (submitted).

[11] X. Fernandez, J. Amat, "Detection of small-size synthetic references acquired with a pixelated device", Optical Engineering 36 (11), pp. 3073-3080, 1997.